tarsus with those above and below, so that the tarsals act like epiphysial pads. Only in mammals epiphyses are universal. Tibia and fibula having their own, the pronounced joint is cruro-tarsal and all the tarsals could be used for a very compact, yet non-rigid arrangement. The advantage of a cap, not merely the introduction of a separate pad, is well recognized in engineering.

Why is it that mammalian material can produce what is denied to the lower classes? In other words, why are there still lower and middle classes? Why have they not all by this time reached the same grade of perfection? Why not indeed, unless because every new group is less hampered by tradition, much of which must be discarded with the new departure; and some of its energy is set free to follow up this new course, straight, with ever-growing results, until in its turn this becomes an old rut out of which a new jolt leads once more into fresh fields.

H. F. Gadow

THE NEW RELATIVITY IN PHYSICS

Ever since Newton's corpuscular theory of light was supplanted, early in the nineteenth century, by the theory that light travels in waves through ether as sound through air, physicists have been endeavoring to obtain direct experimental evidence about this invisible, imponderable ether.

The earth sweeps through space with a velocity of about 2,000 miles a minute; if ether fills all space, it should be possible with the delicate instruments now in our possession to detect an ether drift, an optical effect caused by the motion of the earth through the ether.

Among others, Professors Michelson and Morley[1] tried to detect this ether drift experimentally, but obtained purely negative results. Although they failed to get evidence of an ether, they did obtain new physical facts of an even greater importance, which have caused us to readjust our concepts of space and time.

Let us assume that the sun and earth are at rest in space; it then takes a beam of light about eight minutes to travel through space from the sun to the earth.

If we assume that both sun and earth are in uniform translation through space, that is, that both are in motion along the same straight line, we would expect, since the velocity of light can not be increased or diminished by motion of its source, that a light beam would be longer on its way from sun to earth when it travels in the direction of the motion, and that the light beam would be a shorter time on its way when it travels counter to the motion; in traveling with the motion the light beam would overtake the earth; when the direction of the motion is reversed, earth and light flash would meet.

These deductions, according to the principle of relativity, are not valid, for the facts presented by Michelson's experiments show us that the number of seconds that a light flash is on its way can neither be increased nor diminished when the interstellar space through which the light has to travel is arbitrarily increased or diminished by giving source and observer the same uniform translation.

Newton based his mechanics upon *absolute* space and time,[2] "not that which the vulgar associate with sensible objects." Clerk Maxwell[3] said: "All our knowledge, both of time and place, is essentially relative." Yet he could not free himself from the Newtonian mechanics, and it was not until 1905 that Albert Einstein[4] repudiated the word *absolute,* and out of the "vulgar" ideas of space and time developed the modern theory of relativity. Einstein was then an employee in the patent office at Bern, and it is but fitting that in Switzerland, which has furnished the world with so many timepieces, new thoughts with

[1] *Silliman's Journal,* 34: 337, 1887.

[2] Newton, "Principia," 1: 8, 1822.

[3] Maxwell, "Matter and Motion," p. 30 (Van Nostrand ed., 1892).

[4] *Annalen der Physik,* 17: 905, 1905; *Jahrbuch der Radioaktivitaet und Electronik,* 4: 411, 1907.

respect to the measurement of time should crystallize, and a new time concept be found.

Any regular process of nature may serve as a measure of time; for example, the fall of sand in the hour-glass, the swing of the pendulum, the sun dial, or to be more modern, an ideal watch which is regulated by a perfect spring and balance wheel. Let us imagine we have two perfect watches, one in San Francisco, the other in New York. How can we synchronize or set them so that both will indicate the same instant of time? To synchronize them both at the factory, and send one to New York and the other to San Francisco, will not do, as we shall see later. Since experiment appears to justify the assumption that the velocity of light through interstellar space is always the same, let us use a light flash to synchronize the watch at San Francisco with the one at New York.

At twelve o'clock the observer in New York sends a light flash to San Francisco, where a mirror immediately reflects it back to him; he finds it took thirty thousandths of a second for the light signal to travel to San Francisco and back; he reasons, therefore, that it took fifteen thousandths of a second to travel one way; he then writes the observer in San Francisco to set his watch at twelve o'clock plus fifteen thousandths of a second, as soon as the light flash again sent from New York at twelve o'clock reaches him; the two watches are then in synchronism for observers at these two stations. The simultaneity of an occurrence at New York with one at San Francisco can then be established by the two synchronized watches. The connotation of the word *simultaneity* thus becomes very definite.

In order to bring out nature's facts with regard to time and space, which Einstein has so clearly presented in mathematical form, we have built a model, constructed briefly, as follows: A triple lead-screw, eight feet long, gives motion to the upper or moving system when the crank at the right of the model is in motion. By throwing in the proper gearing at the crank shaft, a second lead-screw supplies motion (toward right or left) to a light particle (L), in the model, a pocket electric lamp resting upon a traveling nut. Two worm wheels meshing with the first lead-screw operate the hands of the lower or stationary clocks, while a pair of spur gear acting as pinions upon a stationary rack move the clock hands of the system in translation when the latter is in motion.

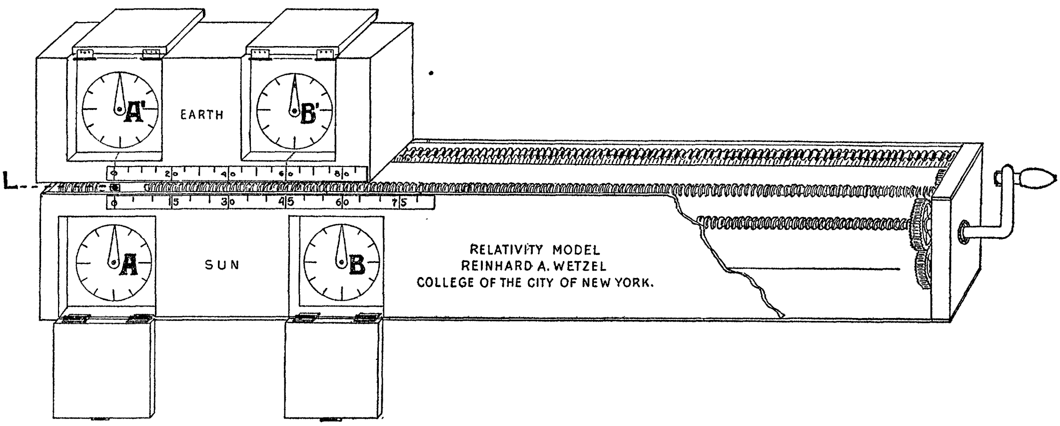

Fig. 1

Following the method of Emil Cohn, of Strassburg,[5] we shall speak of the stationary system as the sun; the two sun clocks are fixed to the sun and are sixty sun miles apart; at each clock station is an observer, sun-man A at the zero station, and sun-man B at the sixty-mile station.

[5] "Himmel und Erde," 23: 117, 1911.

Similarly the moving system may represent an earth always in uniform translation with respect to the sun. At two stations upon the earth sixty earth miles apart are fixed a clock and an observer. A sun-man can see only one earth clock and earth-man at one time,

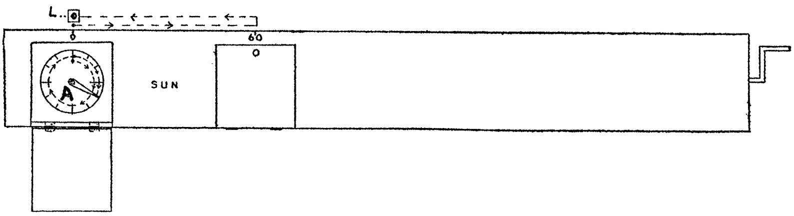

Fig. 2

namely, at the instant earth-man passes sun-man, and *vice versa*. Also, only at the instant an earth-man passes a sun-man can

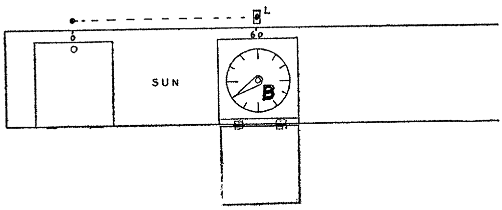

Fig. 3

either make an observation and a comparison of the length and time standards used upon sun and earth.

As the naturalist's picture of a microorganism misrepresents nature as to size, so our model is, in this respect, also a "nature-faker." The orbital velocity of our earth is to the speed of light in interstellar space as one is to ten thousand; but the model arbitrarily represents the earth's velocity to the velocity of the light particle in the ratio of two to three. We must, therefore, interpret our model as a magnifier of nature's facts with respect to space and time.

Suppose A and B upon the sun wish to synchronize their two clocks which are exactly alike in every respect and perfect mechanisms. When A's clock reads 12 (Fig. 2), he sends out the light signal which, reflected by the mirror at the 60-mile station, returns after the hand of A's clock has moved through $12 + 4$, or 16 hours. Assuming that it took the light signal eight hours to go one way, A writes B to be on the lookout; the light signal will again leave at 12 and should reach B at 8 (Fig. 3). When the signal arrives, B sets the hand of his clock at 8, and the two clocks are now in synchronism, and may be used by both observers to establish simultaneous moments of time.

The course pursued by A and B upon the sun at rest is followed by A^1 and B^1 upon the

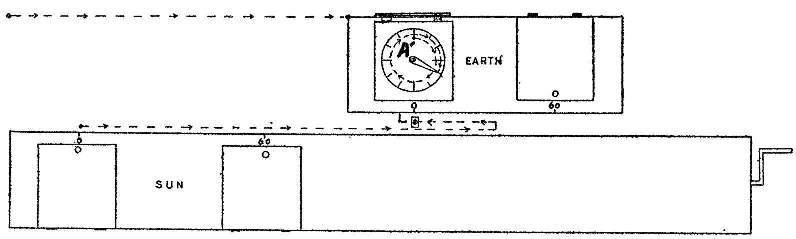

Fig. 4

earth in motion. With their own foot rule A^1 and B^1 have placed their two clocks sixty miles apart, and they too (Fig. 4) find that sixteen hours is required for the passage of the light signal from A^1 to B^1 and return, and that B^1 must set the hand of his clock at 8 (Fig. 5) when the light signal sent by A^1 at 12 reaches

him, in order to set their clocks in synchronism.

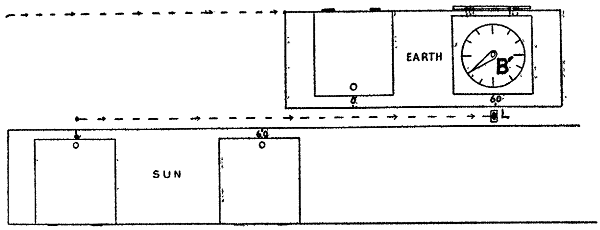

FIG. 5

We are now in a position to measure the velocity of light in both systems, and find that in each case it is 60/8. We can readily believe that all of nature's laws in general, and the velocity of light in particular, should be the same on sun, earth or planet in the Milky Way; but the fact that the earth-man finds the sun clocks slow, and the sun-man finds the earth clocks slow, in the same ratio is the startling contribution of the theory of relativity: that two actions simultaneous upon one system should not be simultaneous when viewed from another system is surprising.

Let us see what the two observers on the sun have to tell us about one of the clocks on the earth.

A and B are sixty miles apart and can not both see the earth clock at the same time; but the earth is a moving system, hence A can compare his clock with the earth clock, and later B can make a similar comparison.

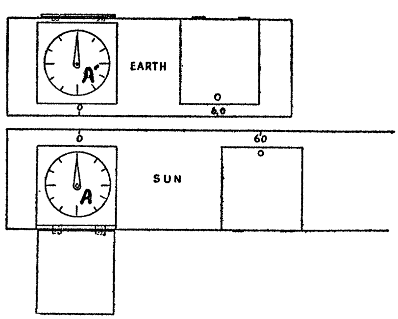

FIG. 6

When the earth clock is opposite A (Fig. 6), the latter finds the hand of his clock at 12, and the hand of the earth clock at 12; as the earth moves on, the earth clock of A^1 will reach a position opposite B (Fig. 7), who finds that the hand of his clock has again reached 12, while the hand of the earth clock has reached only 9; hence A and B establish the fact that twelve hours on the sun are equal to nine hours on the earth; that is, the earth clock runs slow in the ratio of 3 to 4.

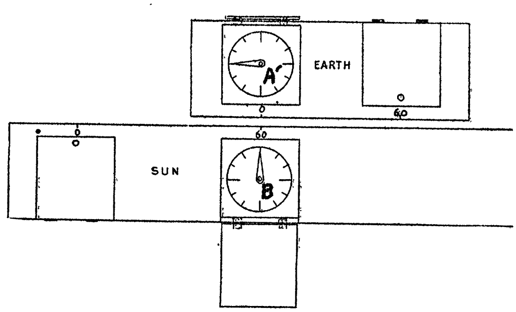

FIG. 7

When the earth-men agree to make observations on one of the sun clocks, they reach a similar conclusion. A^1 and B^1 are sixty miles

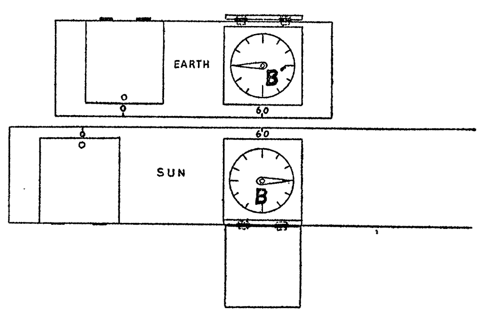

FIG. 8

apart and can not both see the sun clock at the same time; when B^1 comes to a position opposite the sun clock (Fig. 8), the hand of

his clock is at 9, while the hand of the sun clock is at 3; when, as the earth moves on, A^1 comes opposite the sun clock (Fig. 9), he finds that twelve hours have elapsed, for the hand of his clock is again at 9, but the hand of the sun clock has only gone from 3 to 12; in other

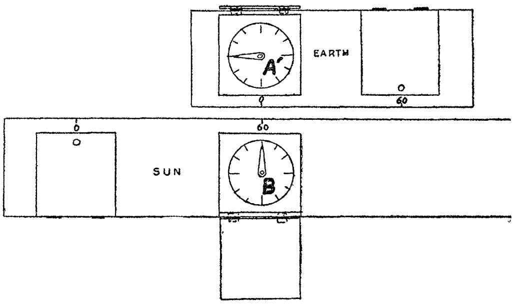

FIG. 9

words, nine hours have elapsed on the sun; hence A^1 and B^1 establish the fact that twelve hours on the earth are equal to nine hours on the sun; that is, the sun clock runs slow in the ratio of 3 to 4.

Since the sun-men and the earth-men make exactly similar statements, each finding the other slow in the ratio of 3 to 4, we must logically conclude that the earth and sun clocks are in reality equivalent, and establish the same unit of time.

The standard of length upon the sun seems, moreover, to be different from that used upon the earth (Fig. 10), but that too is true from

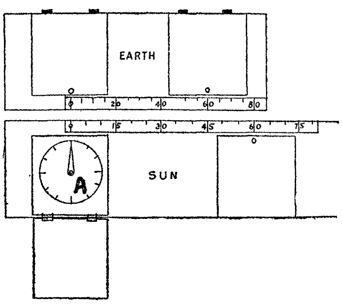

FIG. 10

one view-point (one coordinate system) only; the standards of length as well as of time are in reality equivalent, as we will now proceed to demonstrate.

Let us remember that simultaneity is established only by the clocks.

The sun-men wish to compare their length standard with the standard used upon the earth. The lengths they wish to compare are such that two observers are necessary, one at each end of the scale. A and B decide to compare their scale reading with the scale reading opposite them at the same moment of time. At 12 o'clock A (Fig. 10) finds zero of his scale opposite zero on the earth's scale; B watching his clock finds, when the hand is at 12 (Fig. 11), that 60 on his scale is opposite 80 on the earth's scale. Hence A and B conclude that 60 sun miles are equal to 80 earth miles, or that the earth mile is shorter in the ratio of 3 to 4.

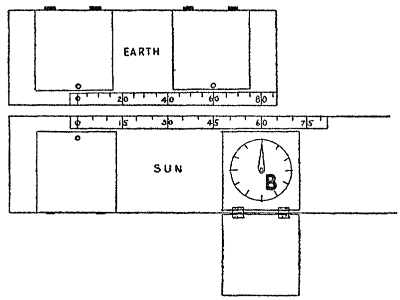

FIG. 11

The earth-men, by similar observations, compare their length standard with the standard upon the sun. A^1, watching his clock

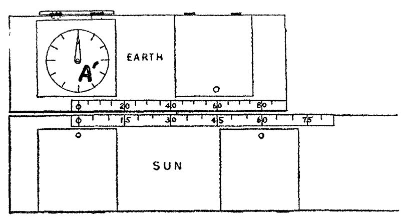

FIG. 12

(Fig. 12), finds when the hand is at 12, that zero on his scale is opposite zero on the sun scale. B^1 finds, when the hand of his clock is at 12 (Fig. 13), that 60 on his earth scale is opposite 80 on the sun scale. Hence they reason that 60 earth miles are equal to 80 sun

miles; or that the sun miles are shorter in the ratio of 3 to 4.

This apparent paradox is due to the fact that we are not accustomed to establishing simultaneity by accurate instruments of time,

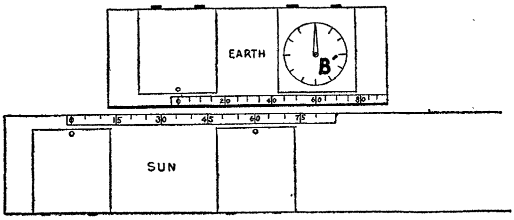

FIG. 13

but rather by a vague "now" which can be established neither by clear thought nor by experiment. We have been thinking absolute time which can not be measured, hence is meaningless; the only time that has meaning is the time we can measure with nature's instruments of time, her uniform processes.

Let us study for a moment the clocks on the moving system; to an observer outside the moving system, the two clocks will be out of synchronism; viewed from the sun (Fig. 14),

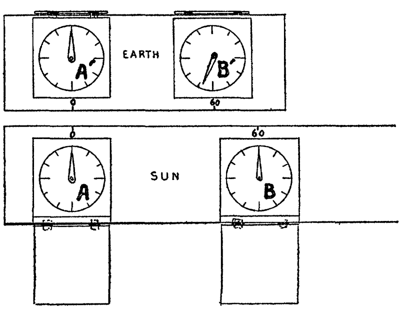

FIG. 14

B^1's clock will be five and one third hours behind the clock of A^1. If, however, A^1's clock be moved to B^1's station, it will no longer be five and one third hours ahead of B^1's clock, but will record the time of that station in perfect agreement with B^1's. In the process of moving from its own station at zero to B^1's station at 60, A^1's clock must therefore have gradually slowed up. *Vice versa,* if B^1's clock be moved to A^1's station, it will on arrival no longer be five and one third hours behind A^1's clock, but in agreement with it; in moving against the direction of the moving system it has gained five and one third hours in time.

Since the clocks are all nature's timepieces, all the clocks in one system (and we can imagine an infinite number of them) move in perfect uniformity. Each point or station on the system has its own particular local or place time (Eigenzeit). If a clock be moved from one station to another, on reaching its new station it records the place-time of that station. It would seem therefore that the impulse which sets the clock in motion in the direction of the moving system acts upon the balance wheel,—or whatever may be the clock regulator, to retard it; and the impulse which sets the clock in motion counter to the moving system acts upon the balance wheel to accelerate it.

The logical deductions that follow from these facts are so startling to the lay mind that I prefer to translate from Einstein himself:[6]

> Give the watch a very large velocity (approximating the velocity of light) so that it travels with uniform speed; after it has gone a long distance give it an impulse in the opposite direction so that it returns to its starting point. We then observe that the hand of this watch during its entire journey to and fro has remained practically at a standstill, while the hand of an exactly similar watch which did not move with respect to the coordinate system (the sun or earth) has changed its position considerably.
>
> We must add: what is true for our watch with respect to time must also be true of any other enclosed physical system, whatever its nature, because in all our thinking the watch was introduced simply as a representative of all physical actions or occurrences. Thus, for example, we could substitute for the watch a living organism enclosed in a box. Were it hurled through space like the watch, it would be possible for the organism, after a flight of whatever distance, to return to its starting point practically unchanged, while an exactly similar organism which remained motion-

[6] Zurich, *Vierteljahresschrift d. Natf. Gesell.,* 56: 1–230, 1911. Reprinted in Berlin; *Naturw. Rundshau,* 28: 285, 1912.

less at the starting point might have given place to new generations. For the organism in motion time was but a moment, if its speed approached the velocity of light. This is a necessary consequence of our fundamental assumptions and one which experience imposes on us.

Let us return to the experiment of Michelson and Morley with which we started. Let us interpret it by means of our model. We have spoken of the sun and earth in uniform translation through space; let us symbolize this by the moving system of our model, the clock at zero being the sun, and the clock at 60 representing the earth; let us send a light flash in the direction of their common translation; it starts from the sun, A^1, at 12 o'clock and reaches the earth, B^1, at 8 o'clock (Fig. 5), thus 8 units of time have elapsed. If we send the light flash against the sun and earth translation, then B^1 becomes the sun and A^1 the earth; the light flash leaves the sun, B^1, at 8 o'clock and again reaches the earth, A^1, at 4 o'clock, 8 units of time having elapsed, exactly as is the case when sun and earth are at rest (Fig. 3).

The assumptions of the principle of relativity are:

1. That among all fixed star systems not one is unique—that as far as physical phenomena are concerned it is immaterial upon what system of reference we base measurement.

2. When a light-pulse or particle travels through empty space the ratio of distance traversed to the time taken to go that distance, both measured in *any* physical system whether considered at rest or in translation, is invariant.

These two assumptions are interpretations of experimental facts, and the conclusions deduced from them as given in this paper cannot be invalidated unless these primary assumptions are shown to be misinterpretations of experiment.

To what conclusion in respect to an interstellar ether[7] does the principle of relativity lead us? That there is no place for the ether hypothesis. If the latter were correct, the ether would possess uniqueness which the first assumption of relativity denies to all bodies occupying space. Primitive man endowed our earth with uniqueness, but the Copernican controversy, though long and bitter, was final. The ether hypothesis has been very helpful to the physicist, and like a crutch to a cripple, it may yet be retained for some time to come, though mathematical analysis has deprived it of even the shadow of an existence.

The theory of relativity says that Michelson's experiment, far from being negative as Michelson thought, was exactly what was to be expected. How could an ether drift be established when the ether had no physical existence?

Relativity theorists are reconsidering Newton's suggestion as to the corpuscular structure of light and a new theory of radiation based upon the idea of quanta [discrete physical energy elements] is now being worked out in Germany and Holland. Newton's theory gave us an easy explanation of the aberration of light, discovered by Bradley, the astronomer royal of England, in 1727. He found that in order to see a star through a telescope, the latter must not be directed along the line from the eye to the star, but must be inclined in the direction of the earth's motion, just as a sportsman aims ahead of his fleeing prey. On the ether hypothesis no satisfactory explanation for aberration can be found.[8] A telescope filled with water was directed toward a star:[9] since the speed of light through water is three-fourths of the speed of light through air, a large variation in the angle of aberration was expected; but the variation found was far from what theory had predicted.

[7] H. A. Lorentz, *Physikalische Zeitschrift*, 11: 1234, 1910; Max Planck, p. 110, "Acht Vorlesungem" (Columbia Lectures, 1910); Geo. B. Pegram, *Educational Review*, 41: 290, 1911; Albert P. Carmon, *School Science and Mathematics*, 13: 1, 1913; M. Laue, *Physik. Zeitschrift*, 13: 118, 1912; Norman Campbell, *Physik. Zeitschrift*, 13: 120, 1912.

[8] H. A. Lorentz, "Electrische Erscheinungen," 1906, p. 1.

[9] Airy, *Proc. Roy. Soc. London*, 20: 35, 1871; 21: 121, 1873; *Phil. Mag.*, 43: 310, 1872.

Poincaré and Favé, Lord Rayleigh,[10] and Brace,[11] each hoped to find effects of the earth's translation through the ether in the double refraction of light by crystals, but were unable to obtain such effects. The phenomena of interference upon which Young and Fresnel based their wave theory of light have not as yet been completely accounted for upon the principle of relativity. Spectroscopists seem to prefer the use of "frequency" to "wave-length" in their descriptions of monochromatic radiation.[12] When any action forcibly ejects from an atom a light particle or an electron spinning in its atomic orbit with the speed of light, it is not difficult to perceive that the ejected light-particle would have a circular motion superimposed upon its apparent translation through interstellar space. Thus the path of a light particle would be spiral or screw-shaped, wave-length would correspond to the pitch of the screw, and frequency to the number of revolutions which the light particle makes per second. Possibly a theory of interference may be worked out along this line.

The new mechanics teaches that the velocity of light, 186,337 miles per second, is our limit of speed; no body in motion can exceed it, and can only with extreme difficulty approach it.

The old mechanics taught that a constant force continually acting upon a body in interstellar space, would make it go faster and faster without limit. The principle of relativity says that a constant force acting upon a body during successive intervals of time meets a greater and greater opposition to its increasing speed; and when it has attained the speed of light the power of this force to produce acceleration is exhausted. There is nothing, of course, in empty interstellar space to prevent a body from continuing forever with the speed once acquired, except collision with another heavenly body, when perchance, the energy of motion changes the cold colliding matter into a radiant sun.

The old mechanics was quite sufficient until the discovery of cathode rays and radium gave us matter in motion outspeeding a thousand times our fastest planet, Mercury. The particles in the stream of cathode rays travel with a velocity of 5,000 miles a second, while those from radium are hurled into space with a speed of 50,000 to 178,000[13] miles per second, and have become in many instances the modern surgeon's scalpel. The physicist, in his search for law with respect to matter, finds it necessary to readapt his mechanics to modern facts.

The question naturally arises: why should the speed of light be set as a limit to the increase of velocity? The answer is that with unlimited speed the possibility arises of a reversal in the order of time. This possibility has been worked out in a curious way by Flammarion.[14] He makes Lumen, an interstellar traveler, an observer of the battle of Waterloo, and then proceeds to show what would happen if, at the close of the battle, he were moving away from the scene with a velocity greater than the speed of light; he would overtake the light which left the battlefield at the beginning of the engagement, and would see the whole fray in a reversed order of time, like a moving picture film run off backward.

Secondly, if Lumen were at rest and the earth were speeding away from him with a velocity greater than that of light, he would see the battle in its natural order, but all would proceed with stately slowness.

Thirdly, if Lumen were at rest and the earth were speeding toward him with a velocity greater than the speed of light, he would again see the battle in the reverse order, as the last fire from the guns would come to Lumen from a point nearer to him than the light from the first volley.

With any experiment thus repeated three times, Lumen would be able to determine whether he were at rest and the earth in motion, or *vice versa;* in other words, he would

[10] Rayleigh, *Phil. Mag.*, 4: 683, 1902.

[11] Brace, *Phil. Mag.*, 7: 328, 1904.

[12] Runge, *Zeitschrift f. Electrochemie*, 18: 485, 1912.

[13] Rutherford, *Physikalische Zeitschrift*, 13: 1178, 1912.

[14] C. Flammarion, ''Stories of Infinity—Lumen,'' p. 74, 1873.

be able to establish absolute motion, a contradiction of the first assumption of the principle of relativity.

Hence in all physical problems where there is a possibility of two solutions, the one which leads to the establishment of an absolute velocity must be rejected, and the alternative solution accepted as valid.

The principle of relativity, besides clearing our minds of the cobwebs of absolute time and space, gives us, through its explanation of physical experiments, a deeper consciousness of the manifoldness of space, in which time is, not the flow of duration suggested by the immortal Newton, but any one of the spacial manifolds so beautifully developed by Heinrich Minkowski in his "Raum und Zeit," and by Wilson and Lewis in the *Proceedings of the American Academy* for 1912.

REINHARD A. WETZEL
THE COLLEGE OF THE CITY OF NEW YORK

GRANTS BY THE BRITISH ASSOCIATION

AT the Birmingham meeting of the British Association for the Advancement of Science grants in aid of scientific research amounting to about $6,000 were made as follows:

Mathematical and Physical Science: Profesor H. H. Turner, seismological observations, £60; Dr. W. N. Shaw, upper atmosphere, £25; Sir W. Ramsay, constants and numerical data, £40; Professor M. J. M. Hill, calculation of mathematical tables, £20; Lieut.-Col. A. Cunningham, copies of the ''Binary Canon'' for presentation, £5.

Chemistry: Dr. W. H. Perkin, study of hydroaromatic substances, £15; Professor H. E. Armstrong, dynamic isomerism, £25; Professor F. S. Kipping, transformation of aromatic nitroamines, £15; A. D. Hall, plant enzymes, £25; Professor W. J. Pope, correlation of crystalline form with molecular structure, £25; Professor H. E. Armstrong, solubility phenomena, £15.

Geology: R. H. Tiddeman, erratic blocks, £5; Professor P. F. Kendall, list of characteristic fossils, £5; Dr. A. Strahan, Ramsay Island, Pembroke, £10; Professor Grenville Cole, old red sandstone of Kiltorcan, £10; G. Barrow, trias of western midlands, £10; Professor W. W. Watts, sections in Lower Paleozoic rocks, £15.

Zoology: Dr. A. E. Shipley, Belmullet Whaling Station, £20; Dr. Chalmers Mitchell, nomenclator animalium, £50; S. F. Harmer, Antarctic whaling industry, £90.

Geography: Professor J. L. Myres, maps for school and university use, £40; Professor H. N. Dickson, tidal currents in Moray and adjacent firths, £40.

Engineering: Sir W. H. Preece, gaseous explosions, £50; Professor J. Perry, stress distributions, £50.

Anthropology: Dr. R. Munro, Glastonbury Lake Village, £20; Sir C. H. Read, age of stone circles, £20; Dr. R. Munro, artificial islands in Highland lochs, £5; Professor G. Elliot Smith, physical character of ancient Egyptians, £34; Professor J. L. Myres, anthropometric investigations in Cyprus, £50; Professor W. Ridgeway, Roman sites in Britain, £20; Dr. R. R. Marett, Paleolithic site in Jersey, £50.

Physiology: Professor E. A. Schäfer, the ductless glands, £35; Professor A. D. Waller, anesthetics, £20; Professor J. S. Macdonald, calorimetric observations, £40; Professor C. S. Sherrington, mammalian heart, £30.

Botany: Professor F. J. Oliver, structure of fossil plants, £15; Professor A. C. Seward, Jurassic flora of Yorkshire, £5; Professor F. Keeble, flora of peat of Kennet Valley, £15; A. G. Tansley, vegetation of Ditchan Park, £20; Professor F. F. Blackman, physiology of heredity, £30; Professor F. O. Bower, renting of Cinchona Botanic Station in Jamaica, £25; Professor W. Bateson, breeding experiments with *Œnotheras*, £20.

Education: Professor J. J. Findlay, mental and physical factors, £30; Dr. G. A. Auden, influence of school books on eye-sight, £15; Sir H. Miers, number, etc., of scholarships, held by university students, £5; Dr. C. S. Myers, binocular combination of kinematograph pictures, £10; Professor J. A. Green, character and maintenance of museums, £10.

SCIENTIFIC NOTES AND NEWS

THE British Association for the Advancement of Science has accepted an invitation to hold the meeting of 1915 at Manchester. It will be remembered that next year's meeting will be held in Australia under the presidency of Dr. William Bateson.

THERE have been called to the Research Institute for Biology, established under the